MEASUREMENT OF SATELLITE PCS FADING USING GPS

Wolfhard J. Vogel and Geoffrey W. Torrence

Electrical Engineering Research Laboratory
The University of Texas at Austin
Austin, Texas 78758, USA

Abstract - A six-channel commercial GPS receiver with a custom-made 40° tilted, rotating antenna has been assembled to make fade measurements for personal satellite communications. The system can measure up to two times per minute fades of up to 15 dB in the direction of each tracked satellite from 10° to 90° elevation. Photographic fisheye lens images were used to categorize the fade data obtained in several test locations according to fade states of clear, shadowed, or blocked. Multipath effects in the form of annular rings can be observed when most of the sky is clear. Tree fading by a *Pecan* exceeding 3.5 dB and 12 dB at 50% and 10% probability, respectively, compared with median fades of 7.5 dB measured earlier and the discrepancy is attributed to the change in ratio when measuring over an area as opposed to along a line. Data acquired inside buildings revealed "rf-leaky" ceilings. Satellite diversity gain in a shadowed environment exceeded 6 dB at the 10% probability.

I. Introduction

To characterize Earth-satellite fading for personal satellite communications (PSC) at L- and S-Band, many campaigns have been carried out with either stratospheric balloons, helicopters, or airplanes employed as *non-orbiting* transmitter platforms [1]. Other measurements have used *satellites of opportunity*, such as INMARSAT's Atlantic or Pacific Ocean Satellite with L-Band pilot tones [2] and NASA's S-Band tracking and data relay satellites (TDRS) [3], or a *dedicated* satellite, i.e., Japan's experimental test satellite (ETS-V) at L-Band [4]. Not much, if any, fade data have been reported which were derived from global positioning satellite (GPS) observations, probably because of their inherent low sampling rate and fade margin. Nevertheless, some information useful for PSC design can be gleaned from such measurements, and at relatively low cost. The most obvious advantage of GPS measurements is the fact that the satellite constellation sweeps out a large part of the sky. This allows the collection at any one location of data at a large variety of elevation and azimuth angles and such data can be used to predict satellite diversity gain of low Earth orbit (LEO) communications systems, when they are combined with specific constellation parameters.

Table 1: Comparison of Transmitter Platforms

	Non-Orbiting Platform (NOP)	Satellites (GEO)	GPS
Frequency	As desired	~1.45 and ~2.05 GHz	1.575 GHz
SNR	>40 dB easily	40 to 20 dB	~21 dB
Sampling interval	1 ms	10 to 1 ms	0.5 to 1 s
Number of simultaneous sources	up to 2	up to 2	up to 6
Elevation angles covered	variable (~5° to 90°)	fixed, depending on location	variable (~5° to 90°)
Information derived	Amplitude, Phase	Amplitude, Phase	Amplitude only
Measurement time	ms	ms	24 h
Cost	High	Medium	Low
Data suitability	primary and secondary statistics, channel simulation	primary and secondary statistics, channel simulation	primary statistics categorized by fade state and elevation angle

A comparison among the different platforms for acquiring fade data is given in Table 1. Although the GPS fade data lack phase information, are obtained at a rate of only 2 or 1 sps and have at best a mere 21 dB signal-to-noise ratio, they come with angular coverage over much of the sky within a 12 hour measurement period, thus making them applicable for LEO or other non-geostationary orbit constellations. In this vein, we describe initial results derived from GPS observations, using a consumer-grade GPS receiver and a fisheye-lens imaging system [5]. These elements were combined to derive cumulative fade distributions categorized by fade state (i.e., clear, shadowed, or blocked).

II. Experimental Setup and Measurement Details

The GPS receiver employed for the measurements is a Trimble Model SVeeSix 6-channel OEM unit supplied with external active patch antenna and RS-232 interface. A computer program monitors the health of the receiver and stores the information decoded by the GPS receiver up to twice per second, such as time, location, satellite positions and signal strengths. The signal level for each monitored satellite is normalized to the maximum expected signal level for this receiver/antenna combination, which is -105.7 dBm. The lowest measurable signal level is 127.6 dBm, corresponding to a dynamic range of 21.9 dB. Backing off by the customary 7 dB results in a measurement fade margin of about 15 dB.

When used in its intended operation as a location determination device, the GPS receiver's antenna is mounted to a horizontal surface, has maximum gain in the zenith direction and decreasing gain with decreasing elevation angle. As fading is expected to increase with decreasing elevation angle, the antenna was canted at an elevation angle of 50° and rotated in azimuth at a rate of 2 rpm. This resulted in a reduction of the data rate from 1 sps to 2 samples per minute. For each satellite the computer program saves the peak signal level up to 2 times per minute. As the measurements are performed by keeping the receiver in the same location for at least 12 hours and as the environment seen by the receiver does not change (statistically speaking), the data rate reduction is irrelevant. The system with the rotating tilted antenna was used to make measurements at several locations, including inside two office buildings, close to a long three-story building, inside a vehicle, and several others at sites impacted by tree shadowing or object blockage.

To relate the observed signal levels to each fade state (*Clear*, *Shadowed*, or *Blocked*) in specific azimuth and elevation angle directions, fisheye lens images were also taken from the approximate position of the receiving antenna at each measurement site. The images were divided manually into fade state regions and used to categorize the signal level observations.

Using only a six-channel GPS receiver has biased the data to make fewer measurements available for the blocked state, however, especially at locations where only a part of the sky is blocked. The GPS receiver will try to acquire and use the six strongest signals that give a strong solution, hence the weakest, i.e., the blocked signals, do not get measured. There are two strategies for dealing with this problem. One is to make the measurements with a 10-channel receiver. As the maximum number of satellites visible is usually 10 or less for elevation angles above 5°, even the weakest satellites would be measured (within the dynamic range of the system).

III. Results

Details for three of the GPS experiments have been summarized in Table 2. For each measurement set, two types of figures have been included: (1) an overlay of the fisheye image with the signal strength encoded azimuth-elevation traces of the GPS satellites and (2) a plot of cumulative distribution functions categorized by fade state (clear, shadowed, or blocked) with the addition of a cdf for the indeterminate transition regions between any two fade states and the overall cdf. The transition region is defined as the area contained within about ±4° from the line separating the fade state regions.

The fisheye overlay images are in color and the GPS satellite traces are color-coded in 2 to 3 dB steps of signal strength. Common features in the images are elevation angle contours at 30° and 60° and north is at the top and west on the right. Due to the orbit inclination of the GPS constellation and Austin's latitude of 30.4°N, no satellites appear in the northern-most part of the sky.

Measurement Set 1 in Figure 1 was acquired under a canopy of trees. More than 96% of the measurement points are categorized as shadowed. The fade cdf has a median of 1.5 dB and a 1% value of 10 dB. Clear sky is seen in the second set, taken north of a water tower and depicted in Figure 2. It demonstrates the blockage by the water tower and also shows "cold-spots" in the clear sky region due to multipath reflections. The cdf, for the blocked and clear states has a 1% value of 13.5 dB and 4 dB, respectively. A third measurement was performed on the top-floor of a 6-story office building, where the receiving antenna was placed on the sill of a south window. There was no tree-shadowing and the glass was plain plate glass. The fisheye pictures and resulting cumulative distribution functions are shown in Figure 3. At this site some energy was received through the reinforced concrete ceiling. Diffraction effects along the window edges cause the GPS signal strength to vary over the directions defined by the window aperture, but the strongest signals are close to the clear-path level. Due to these multipath effects, the clear state fades at the 10% probability have attenuations exceeding between 6.5 and 7.5 dB.

Table 2: Details for Selected Measurement Sites

Set	Location	Characteristic
1	Under *Pecans* and *Oaks*	Shadowing
2	North of a water tower	Clear & Blockage
3	South window, top floor, no trees	Building Penetration

Figure 1: Tree-shadowed location under Pecans and Oaks.

Figure 2: Clear LOS with some blockage by a water tower.

Figure 3: View from a southern window on the sixth and top floor of an office building.

IV. Diversity Analysis

The GPS data collected in the shadowed environment at Site 1 (Figure 1) have been analyzed for satellite diversity gain. There are 7 hours of data at 1 sample per minute in the set. At any one time, typically 5 or 6 satellites were visible. Output from an orbit program, *SATPRO* [8], predicted GPS satellite trajectories. The orbit data were used to randomly select two theoretically visible satellites (elevation angle > 5°) once every minute. The signal strengths for the chosen satellites (see Figure 1) were binned into three separate histograms: one for each satellite and a joint histogram for the stronger signal of the two. The cumulative distribution functions derived from the three histograms are plotted in Figure 4. The benefits of satellite diversity in a shadowed environment can be appreciated by comparing the two single-satellite CDFs (solid line, filled circles and dashed line, diamonds) to the joint distribution (solid line, empty circles), defined by the stronger of two different satellite signals. Because the entire sky was shadowed and a new satellite pair was randomly chosen every minute, the distributions are constellation independent. At the 10% probability, over 6 dB diversity gain is achieved.

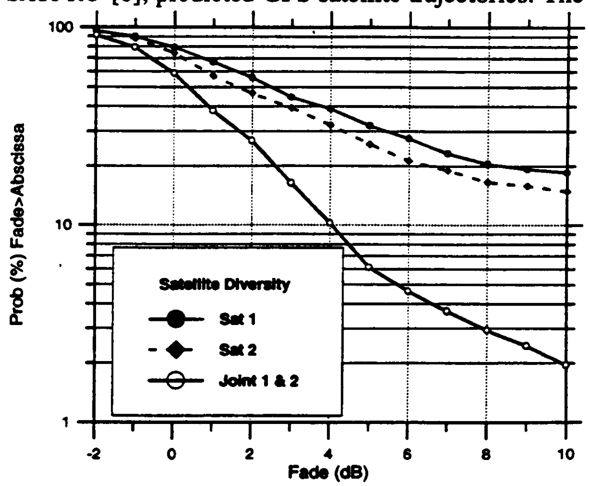

Figure 4: Satellite diversity gain in shadowed environment.

V. Conclusions

A six-channel GPS receiver was configured to make fade measurements for personal satellite communications propagation research. This included tilting the antenna 40° from vertical and rotating it in azimuth to mitigate the loss of measurement sensitivity due to the antenna pattern. Although the data rate was reduced to one measurement in 15 seconds per satellite, this did not impact the results, as the GPS fade measurements are limited to a stationary receiver anyway. The advantage of the GPS measurements is that over the course of a day transmitters are moving over much of the sky and allow the collection of fade data with varying azimuth and elevation angles. The system can measure fades up to 15 dB. By combining the fade results with fisheye lens images taken at the same spot, the fades could be categorized according to the fade state in a particular direction.

We found the median tree attenuation to be less than that measured previously by scanning a receiver laterally across the shadow zone of the tree. This may be due to the fact that the GPS measurement is an area (or solid angle) measurement and includes a larger fraction of less attenuating tree periphery than the linearly scanning measurement. In the open, with clear sky conditions, the GPS measurements revealed annular rings and isolated spots of fading due to (specular) multipath reflections. In rooms with plain glass the signal was strongest within the window aperture, but diffraction affected the signal over the entire region of visible sky. Satellite diversity gain in a shadowed environment was found to be greater than 6 dB at the 10% probability level. The measurement system could be improved in two ways. For one, using a ten-channel receiver would provide more blocked fade state data, especially at locations that are only partially blocked. With the six-channel receiver, often all six channels are locked to satellites which are in the clear or shadowed part of the sky, leaving no channel to search for weaker blocked signals.

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